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New Particle Searches at CDF

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NEW PARTICLE SEARCHES AT CDF

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Abstract

We present results from searches for the top quark, supersymmetric particles, and new gauge bosons at the Collider Detector at Fermilab (CDF).

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1 Introduction

The Fermilab proton-antiproton collider possesses the highest center-of-mass energies in the world, and this makes it an excellent hunting ground for new particles. With the large data sample collected by the Collider Detector at Fermilab (CDF), extensive searches can be made for the top quark and particles from numerous models that extend the Standard Model. In this paper, we first describe the search for the top quark at CDF. We next present the search for supersymmetric particles. Finally, the search for additional heavy vector bosons, the W' and the Z' , is described.

2 Search for the Top Quark

The dominant production mechanism of top quarks at the Fermilab Collider is the production of $t\bar{t}$ pairs from gluon fusion or quark-antiquark annihilation. Leptonic decays of both top quarks lead to events with a spectacular signature of two high transverse energy leptons plus missing transverse energy ($\not\!\!E_t$) and possibly soft b-quark jets. If one of the top quarks decays leptonically, and the other hadronically, the signature will be that of a lepton+multijet+$\not\!\!E_t$ event.

CDF has published results from two searches for the top quark. The analysis [1] of electron+two jet+$\not\!\!E_t$ events proved to be consistent with QCD production of a W boson plus two jets. For top quark masses smaller than the W mass, the transverse mass distribution of the e+$\not\!\!E_t$ system is softer for $t\bar{t}$ than for W+jets events. The resulting upper limit on the $t\bar{t}$ cross section excluded a Standard Model top quark in the range 40 GeV $< M_t <$ 77 GeV. This method loses its sensitivity with M_t approaching M_W, as the transverse mass distributions become indistinguishable.

The second analysis [2] searched for high transverse momentum ($>$ 15 GeV) $e+\mu$ events, which has a very small contribution from background sources. Figure 1 shows the CDF data with electron $E_t >$ 15 GeV and muon $P_t >$ 5 GeV. One candidate event with $>$ 15 GeV in both legs was found. The limit on the top quark mass from this channel is $M_t >$ 72 GeV.

The straightforward extension of the $e\mu$ analysis is to search for the top quark in the dielectron (ee) and dimuon ($\mu\mu$) channels. As with the $e\mu$ analysis, the dilepton P_t was required to be greater than 15 GeV on both legs. The predominant backgrounds are Z decays, but Drell-Yan, Υ, and J/ψ backgrounds are non-negligible. A simple dilepton mass cut around the Z peak (75 GeV $< M_{ll} <$ 105 GeV) removes most of the background with little impact on the $t\bar{t}$ signal. Two additional cuts improve the signal to background ratio further, requiring $\not\!\!E_t >$ 20 GeV, and requiring the azimuthal opening angle, $\Delta\phi_{ll}$, to be in the region $20° < \Delta\phi_{ll} < 180°$. After all of these cuts, there are no ee or $\mu\mu$ events remaining in the data. The combined limit from the $e\mu$, ee, and $\mu\mu$ channels is $M_{top} >$ 84 GeV at the 95% confidence level.

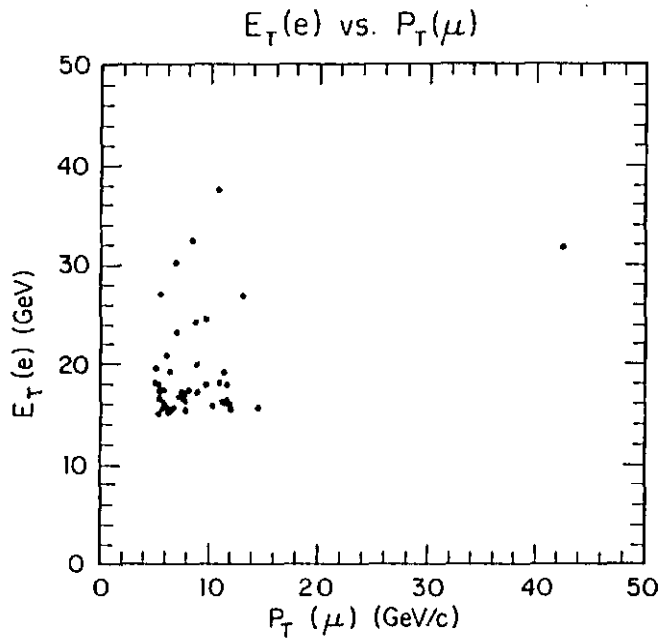

Figure 1: Electron transverse energy vs. muon transverse momentum for the CDF data with an integrated luminosity of 4.1 pb^{-1}.

Finally, the CDF experiment has searched the $e + jets$ and $\mu + jets$ samples for additional low p_t muons, as a possible tag of the bottom quark in a $t\bar{t}$ event. Backgrounds to these soft muons from decay-in-flight of pions and kaons and hadronic punchthrough are reduced by rejecting events where the muon is within ΔR ($\eta - \phi$ space)< 0.6 of either of the two leading jets. Figure 2 shows the distribution of ΔR between the soft muon and the nearest of the two leading jets for the CDF data and for $M_{top} = 90$ GeV $t\bar{t}$ Monte Carlo. No candidates were found. The result of this search, combined with the previous dilepton results, extends the CDF top quark mass limit to $M_{top} > 89$ GeV at the 95% C.L. [3] Figure 3 shows the upper and lower bounds of a theoretical calculation of the $t\bar{t}$ cross section, [4,5] as well the cross section limits described in this paper.

3 Search for Supersymmetric Particles

Supersymmetry [6] (SUSY) is a proposed symmetry that links fermions and bosons. For each known fermion (boson) there is a corresponding supersymmetric boson (fermion) partner. For example, the quark, gluon, and photon have as SUSY partners the squark ($\tilde{q}$), gluino ($\tilde{g}$), and photino ($\tilde{\gamma}$). The masses of the SUSY partners are not predicted by the theory. In the minimal SUSY model, all six squarks have the same mass and the photino is lightest SUSY particle. Rigorous conservation of a SUSY quantum number is assumed, so the photino is stable and will escape detection. Pair production of squarks and gluinos are the dominant source of SUSY particles at $p\bar{p}$ colliders. The assumed decay of the gluino is $\tilde{g} \rightarrow q\bar{q}\,\tilde{\gamma}$, and the squark decay modes are $\tilde{q} \rightarrow q\tilde{g}$ (for $M_{\tilde{q}} > M_{\tilde{g}}$) and $\tilde{q} \rightarrow q\tilde{\gamma}$ (for $M_{\tilde{q}} < M_{\tilde{g}}$). The final state

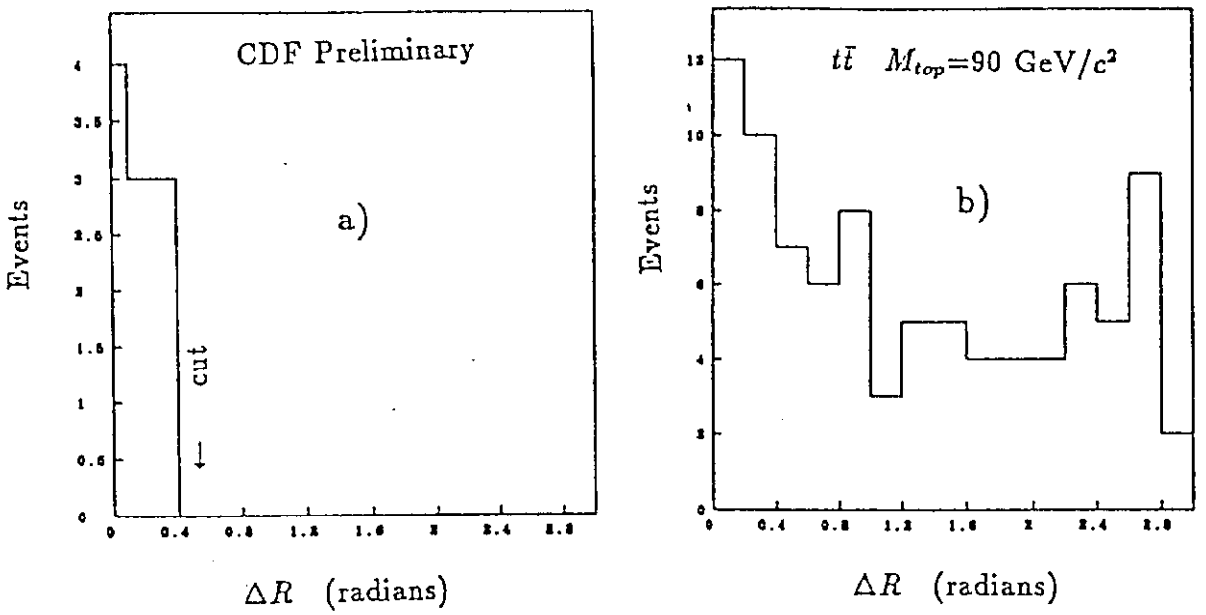

Figure 2: Distribution of ΔR, the distance in $\eta - \phi$ space between the low P_t muon and the nearest of the two leading jets in the top quark search. a) CDF data with integrated luminosity of 4.1 pb^{-1}. b) $t\bar{t}$ Monte Carlo with integrated luminosity of 250 pb^{-1}.

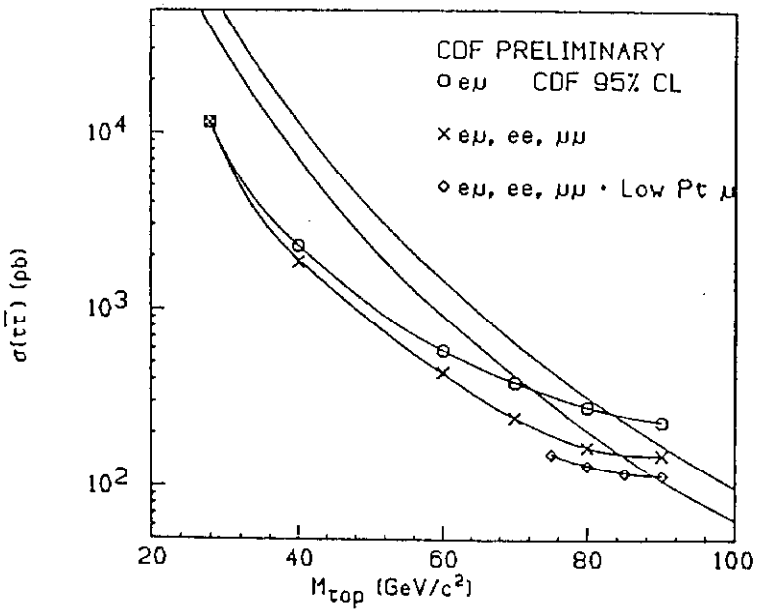

Figure 3: Experimental upper limits on $t\bar{t}$ cross section (@ 95% C.L.) as a function of top quark mass. Superimposed are the upper and lower bounds from a theoretical calculation. The top quark mass limits are derived by finding the intersection between the experimental upper limit and the theoretical lower bound.

then consists of normal quarks and gluons, and photinos which escape detection. Thus SUSY events will contain jets plus missing transverse energy.

CDF has searched for squarks and gluinos in the context of the minimal SUSY model described above. The data sample consisted of events with $\not\!\!E_t > 40$ GeV and at least two jets with $E_t > 15$ GeV. Events containing identified electrons or muons were removed. The remaining 98 events in this sample are consistent with background expectations: $86 \pm 14 \pm 12$ events from W and Z decays and 4 ± 4 events from QCD processes. Further cuts were then applied to enhance any SUSY signal over background. Two cases were considered separately. For the case of $M_{\tilde{q}} < M_{\tilde{g}}$, the missing transverse energy cut was raised to $\not\!\!E_t > 100$ GeV. Three events passed this cut, with an expected background of 1.3 ± 1.3 events. A SUSY signal for $(M_{\tilde{q}}, M_{\tilde{g}}) = (150,400)$ GeV would give 4.9 events. In the second case, $M_{\tilde{q}} < M_{\tilde{g}}$, four or more jets with $E_t > 15$ GeV were required in the event selection. Two events passed this cut, with an expected background of 1.3 ± 1.3 events. A SUSY signal for $(M_{\tilde{q}}, M_{\tilde{g}}) = (500,150)$ GeV would give 5.6 events.

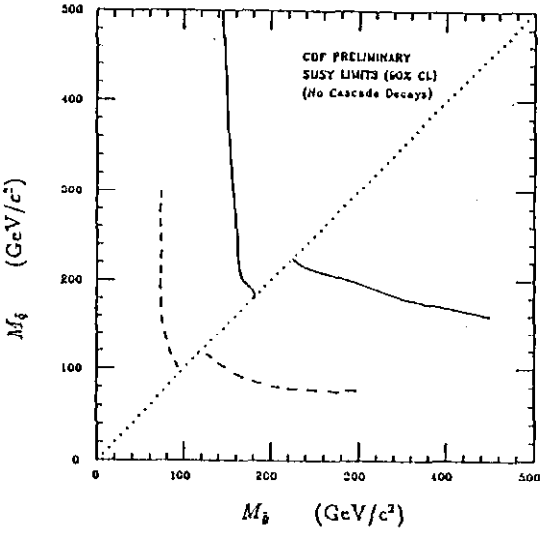

Figure 4: The 90%-C.L. excluded region in the gluino-squark mass plane. The solid line is a preliminary result based on 1988-1989 data. The dashed line is the result from the previous 1987 data.

Figure 4 shows the region excluded at the 90% confidence level by the CDF experiment based on the non-observation of a SUSY signal. The discontinuity along the line $M_{\tilde{q}}=M_{\tilde{g}}$ is due to the different acceptances of the two cases considered. The asymptotic 90% C.L. mass limits are $M_{\tilde{g}} > 150$ GeV (independent of $M_{\tilde{q}}$), and $M_{\tilde{q}} > 150$ GeV (for $M_{\tilde{g}} < 400$ GeV). [7]

It has been noted [8] that if squarks and gluinos are heavy enough, they could decay into heavy SUSY particles (charginos and neutralinos) which would

themselves decay into the lightest SUSY particle. It is expected that the effect of such cascade decays would lower the squark and gluino mass limits by $\approx$ 30 GeV.

4 Search for New Gauge Bosons

Additional charged and neutral vector bosons, W' and Z' , arise in many extensions of the minimal Standard Model. Experimentally, heavy W-like particles would appear as a peak in the lepton-neutrino transverse mass distribution, above the standard W peak. Similarly, a heavy Z-like particle would peak in the dilepton invariant mass distribution, above the standard Z resonance.

The CDF experiment has searched for a W' signal in a sample of events containing an electron or muon with $E_t > 30$ GeV and with missing transverse energy $\not\!\!E_t > 30$ GeV. The data are well explained by W production alone in both the electron and muon sample. The absence of events at high transverse mass allows CDF to set limits on W' production. Figure 5 shows the 95% C.L. limit for the production times branching ratio for $W' \rightarrow l\nu$. The limits are shown for the individual electron and muon channels, and the combined limit. With Standard Model couplings and branching ratios, the lower limit on the W' mass is 520 GeV.

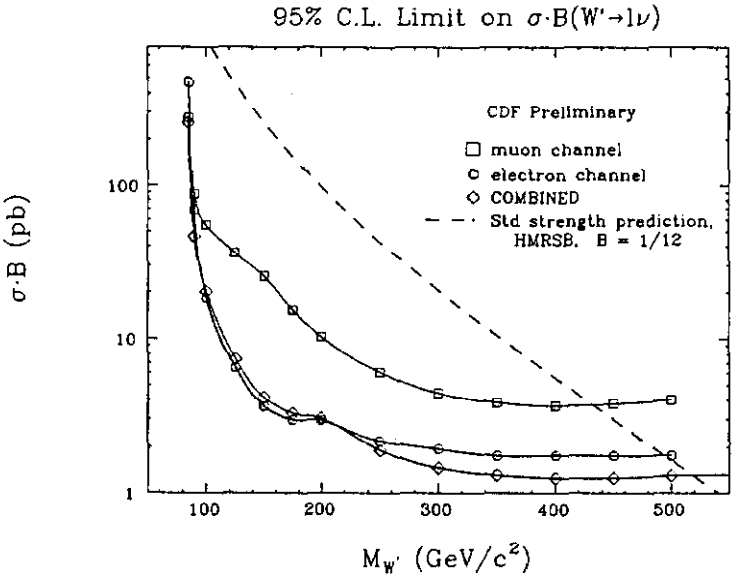

Figure 5: 95% confidence level limits on W' production times branching ratio. The dashed line is the prediction from the HMRSB structure functions, assuming Standard Model couplings and branching ratios.

The similar search for the Z' has been conducted in the dielectron sample. The integral dielectron invariant mass distribution for the CDF data is shown in figure 6, along with a theoretical prediction of Z boson and Drell-Yan production. The data are consistent with the theory. No events with a dielectron mass above

200 GeV were observed and a 95% C.L. lower limit on a Z' mass of 380 GeV was obtained with Standard Model couplings and branching ratios. [7]

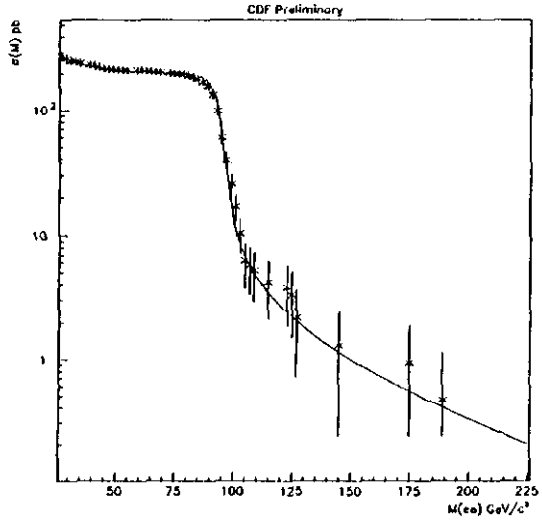

Figure 6: Comparison of the integral dielectron invariant mass distribution for CDF data and Z/Drell-Yan $\rightarrow$ ee Monte Carlo.

5 Conclusions and Prospects

The CDF experiment at the Fermilab $p\bar{p}$ Collider has searched for the top quark, supersymmetric particles, and heavy vector bosons. The result of these searches have yielded no new particles, but the mass limits in all cases are the most stringent in the world today. CDF anticipates collecting at least 25 pb^{-1} in the next collider run at Fermilab. The data from this run should allow CDF to search for the top quark in the mass region of 90-150 GeV. The mass reach for other new particles will also be significantly increased with the new data.

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